C O I N V E D I III International Congress on Construction and Building Research

Escuela Técnica Superior de Edificación
Universidad Politécnica de Madrid
Avda. de Juan de Herrera, 6 28040 Madrid, Spain

14th-16th of December 2015

TECHNOLOGICAL AND CONCEPTUAL LEAPS ON BRIDGES: LEADING SECTOR OF TECHNOLOGICAL EXPERIMENTATION DURING THE LAST TWO CENTURIES

Humanes Cisnal, Alberto(1)

(1) AHC arquitectura, ahcarquitectura@gmail.com.

Keywords: Large Spans; History; Materials; Evolution.

1. Introduction – Throughout the whole history of man, all constructed buildings have been conditioned by technical limitations [1]. In the nineteenth century, with the inclusion of iron in the construction field, structural layouts subjected to traction could be used for the first time in history. Before then, any building was based on compressive forces, such as structural systems like the arch, the vault and the dome, which through an intuitive adaptation to the antifunicular scheme, large spans can be constructed by using compressive forces. Centuries of experimentation have allowed us to evolve from the Roman arches (very thick) with the ability to resist many antifuniculars, to the Gothic structures (very thin) designed for a very limited set of scheme loads.

The qualitative leap enabled by new materials was introduced with arch bridges such as in Coalbrookdale Bridge (England, 1775), which reinterprets a previous structural model with the advantages of the new material [2]. Today the arch continues to be used as an efficient system for large spans, as in the case of the Chaotianmen Bridge (China, 2009), that covers 552 meters (Table 1). But this dimensional range is very small compared to other constructive solutions that exceed this structural type. In fact, the arch from 1811 has been surpassed by another structural layout, the suspension bridges [3].

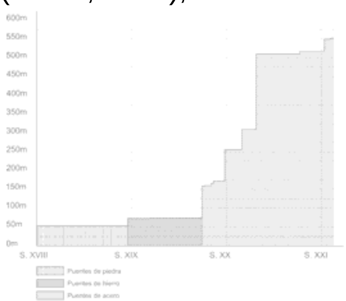


Table 1 Spans on arched bridges

Suspension bridges have evolved through advances in materials and the ways in which these materials are produced [4]. In this regard, the first suspension bridges employing chains later used bars as linear links. The bar bridge built over the valley of Sarine in Fribourg (Switzerland, 1834) managed to cover 265 meters.

But in the mid-nineteenth century, the new material, the cables, got in the lead in the dimensional aspect, and progressed rapidly throughout the nineteenth century in its internal configuration and its wire drawing process. The cables have become a vital resource for the conception of the largest bridges in the world.

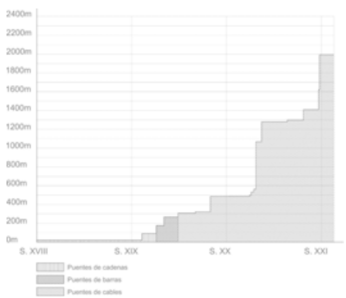


Table 2 Spans on suspension bridges

Since suspension bridges got in the lead by covering a record distance of 306 meters with the bridge Wheeling (United States, 1849), there have been great strides until today, and now the Great Akashi Kaikyo Bridge (Japan, 1998) covers 1991 meters (Table 2). These dimensional ranges now are technically surmountable, as evidenced by the bridge project to the Strait of Messina (Italy), that is designed and calculated with spans of 3.3 kilometers.

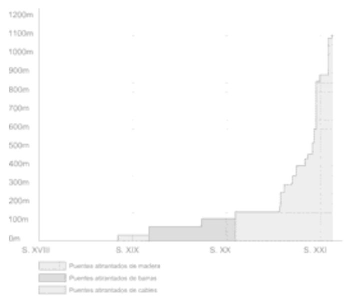


Table 3 Spans on cable-stayed bridges

In this scenario it is necessary to take into account the great impact of costs and especially the formwork. In this aspect, employing wires cable-stayed bridges (Table 3) offer an economical option. This typology doesn't reach the dimensional ranges of suspension bridges [5], but considerably reduces costs by not requiring formwork. One of the most common ways to build these bridges is using successive cantilever, usually a very advantageous system.

Over the last two centuries, the bridges have been the leading reference for technology [6], they are the testing ground where limits of what's workable are plotted. This has an impact on subsequent architecture that benefits from this experimental work [7].

2. Methods – This study is the result of a long process of collecting examples of bridges built along the eighteenth, nineteenth and twentieth centuries, establishing a direct link with the advances produced, both in materials and in construction techniques. Throughout the centuries, bridges have been a reflection of the technological landscape of the moment; in this experimental field the largest spans and the limits of what can be constructed are being obtained. So a series of diagrams were elaborated to compare the dimensional limits of each technique, allowing to see the influence of certain developments and historical events in the evolutionary process of the bridges. This study lets you see which solution is best at all times when having to cover a determined span and see which options are available.

3. Results and Discussion – As a result of the study, the diagrams with the maximum reachable spans for each of the techniques explained during the last two centuries are obtained. In addition, the dimensional limit for each construction technique is also highlighted (Table 4), describing the historical overview in which we find ourselves today.

4. Conclusions – Over the last two centuries, the field of architecture moves away gradually from the technical limitations. Bridges have been a field in which there has been a greater technical experimentation. History and technology are inseparable for understanding the evolution of architectural spatiality. The technological variety now offers a wide range of options, each with particular aspects, whether related to the dimensional ranges, construction or economic conditions. The construction is conceived from a technical point of view as the election of the most appropriate choice for an specific problem. Therefore, a good understanding of the technical landscape is necessary for understanding the framework in which architectural production is performed.

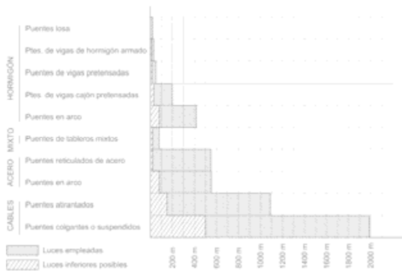


Table 4 Ranges of spans according to the typology

References

[1]. Billington D. (1983). La torre y el puente. Princeton University Press. United States.

[2]. Argüelles R. (2001). Estructuras de Acero, uniones y sistemas estructurales. Bellisco editions. Madrid.

[3]. Pevner N. (1958). Pioneros del diseño moderno. Ediciones Infinito (Primera edición, 1936). Buenos Aires.

[4]. Elices M. (2008). De las cuerdas de cáñamo a los hilos de araña. La Ciencia e ingeniería de los materiales. Real Academia de Ciencias.

[5]. Bejumea J. M., Chio G., Maldonado E. (2012). Puentes extradosados: evolución y tendencias actuales. Tecnura vol. 16 nº 33 (julio/septiembre de 2012). Bogotá.

[6]. Fernández F. Los Grandes Puentes de Hierro del Ferrocarril. Spain.

[7]. Bullington P. y Goldsmith M. (1986). Technique and Aestetics in the Design of Tall Buildings. Institute for the Study of the High-Rise Habitat. United States.

TECHNOLOGICAL AND CONCEPTUAL LEAPS ON BRIDGES: LEADING SECTOR OF TECHNOLOGICAL EXPERIMENTATION DURING THE LAST TWO CENTURIES

Alberto Humanes Cisnal

Throughout the whole history of man, all constructed buildings have been conditioned by technical and material [2] limitations. In the nineteenth century, with the inclusion of iron in the construction field, structural layouts subjected to traction could be used for the first time in history. Before then, any building was based on compressive forces, such as structural systems like the arch, the vault and the dome, which through an intuitive adaptation to the antifunicular scheme, large spans can be constructed by using compressive forces. Centuries of experimentation have allowed us to evolve from the Roman arches (very thick) with the ability to resist many antifuniculars, to the Gothic structures (very thin) designed for a very limited set of scheme loads.

The qualitative leap enabled by new materials was introduced with arch bridges such as in Coalbrookdale Bridge (England, 1775), which reinterprets a previous structural model with the advantages of the new material. Today the arch continues to be used as an efficient system for large spans, as in the case of the Chaotianmen Bridge (China, 2009), that covers 552 meters [1] [4]. But this dimensional range is very small compared to other constructive solutions that exceed this structural type. In fact, the arch from 1811 has been surpassed by another structural layout, the suspension bridges. Suspension bridges have evolved through advances in materials and the ways in which these materials are produced. In this regard, the first suspension bridges employing chains later used bars as linear links. The bar bridge built over the valley of Sarine in Fribourg (Switzerland, 1834) managed to cover 265 meters.

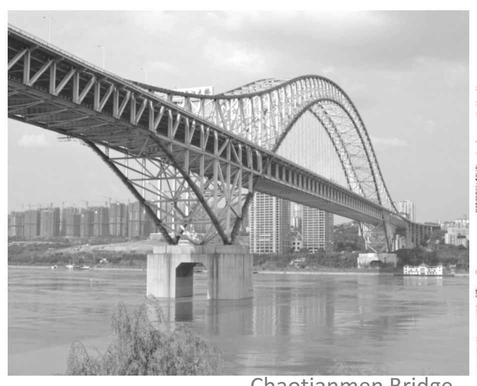
But in the mid-nineteenth century, the new material, the cables, got in the lead in the dimensional aspect, and progressed rapidly throughout the nineteenth century in its internal configuration and its wire drawing process. The cables have become a vital resource for the conception of the largest bridges in the world.

Since suspension bridges got in the lead by covering a record distance of 306 meters with the bridge Wheeling (United States, 1849), there have been great strides until today, and now the Great Akashi Kaikyo Bridge (Japan, 1998) covers 1991 meters [1] [4]. These dimensional ranges now are technically surmountable, as evidenced by the bridge project to the Strait of Messina (Italy), that is designed and calculated with spans of 3.3 kilometers.

In this scenario it is necessary to take into account the great impact of costs and especially the formwork. In this aspect, employing wires cable-stayed bridges [1] [4] offer an economical option. This typology doesn't reach the dimensional ranges of suspension bridges, but considerably reduces costs by not requiring formwork. One of the most common ways to build these bridges is using successive cantilever, usually a very advantageous system.

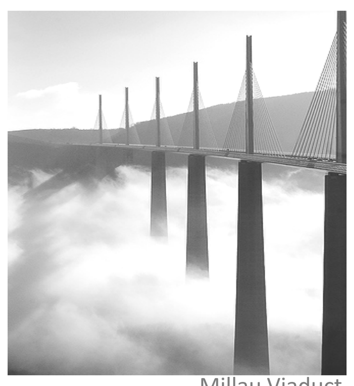
Over the last two centuries, the bridges have been the leading reference for technology, they are the testing ground where limits of what's workable are plotted. This has an impact on subsequent architecture that benefits from this experimental work.


Coalbrookdale Bridge

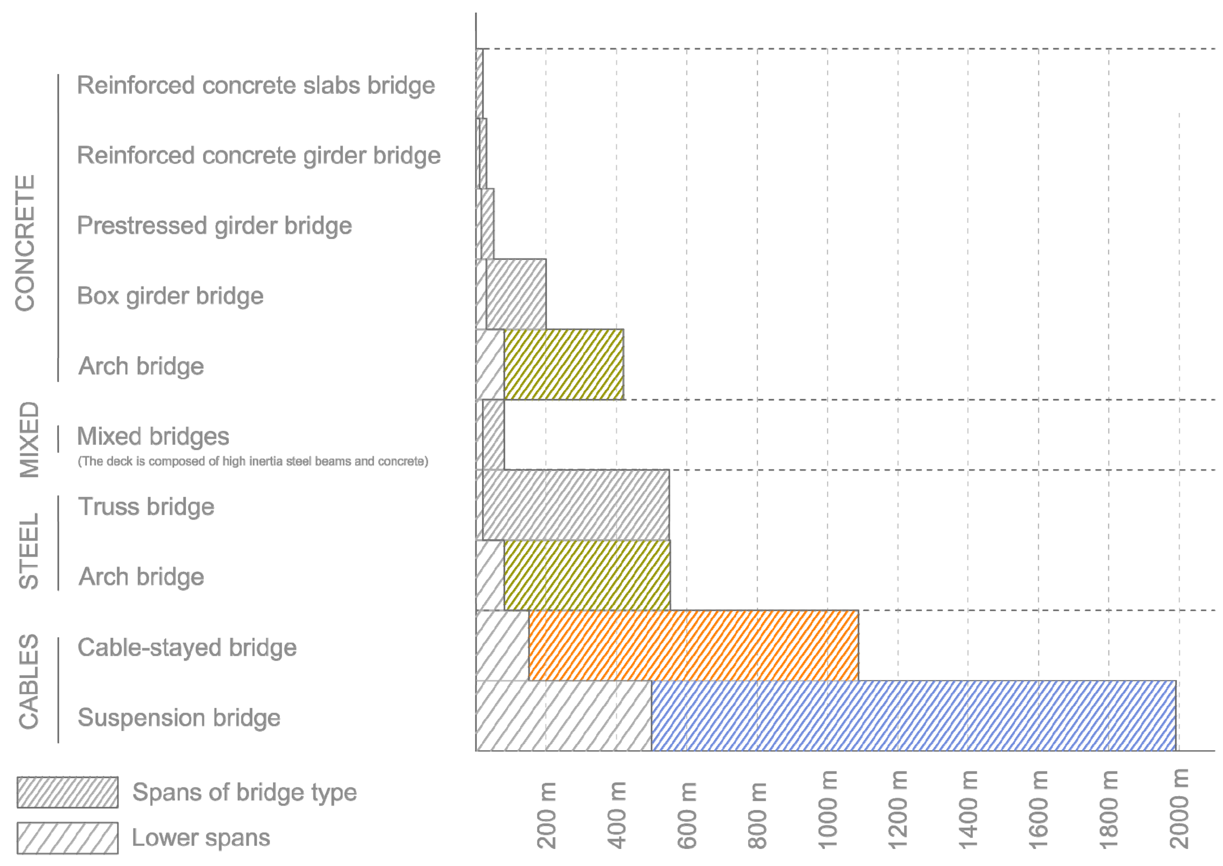

Chaotianmen Bridge


Brooklyn Bridge


Akashi Kaikyo Bridge

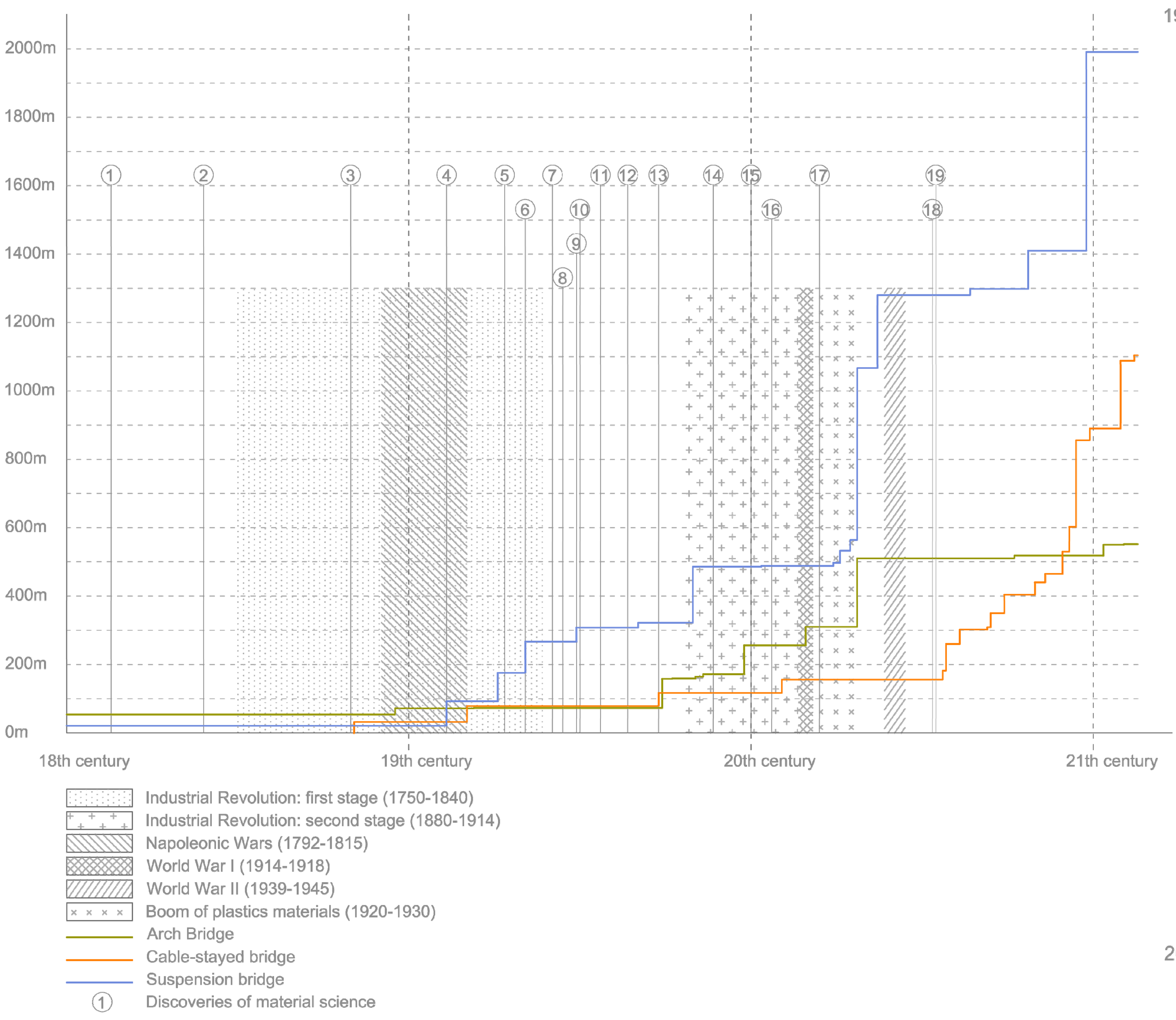

Millau Viaduct

[3] Structural Systems and dimensions

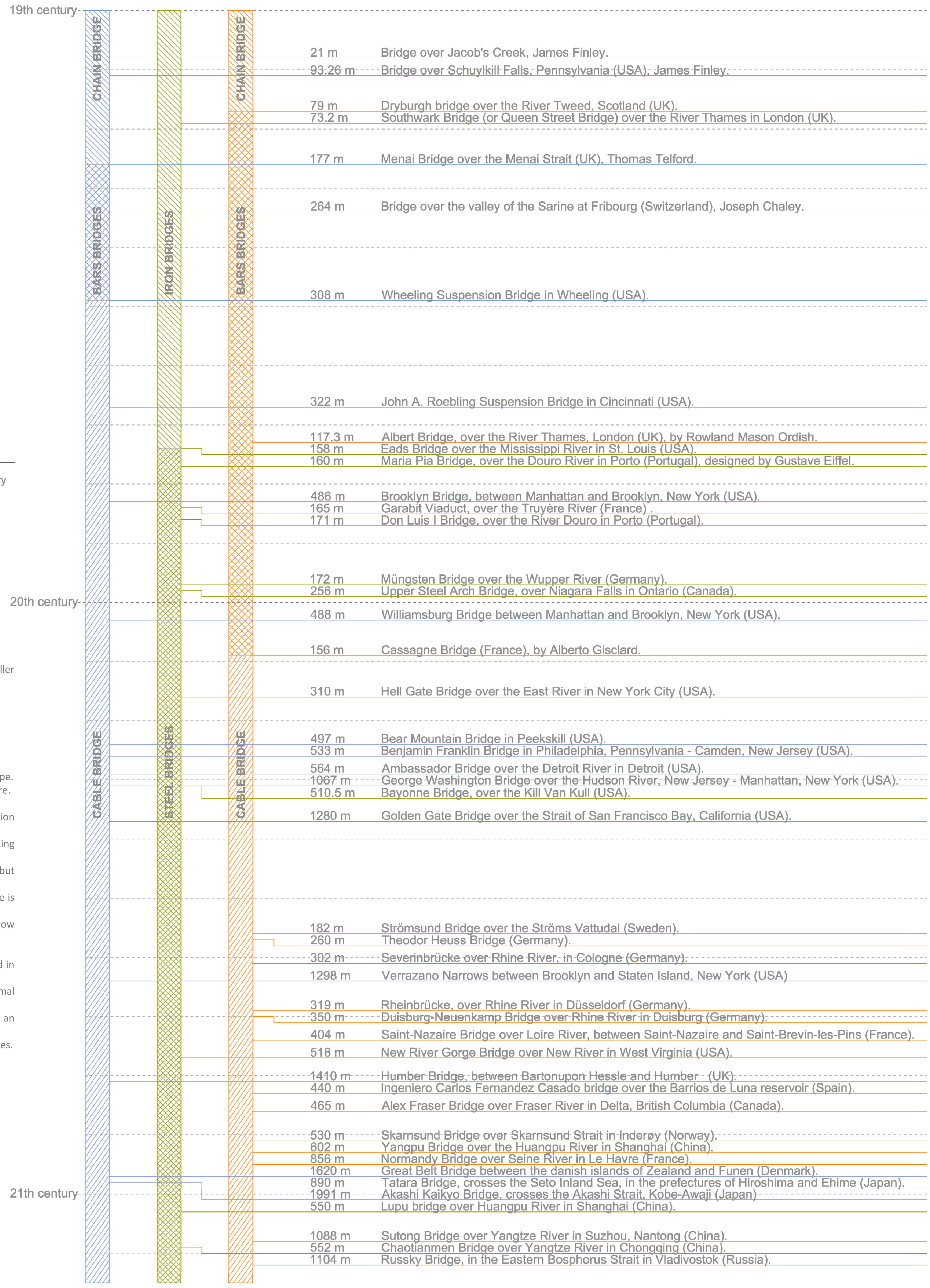


Conclusions – Over the last two centuries, the field of architecture moves away gradually from the technical limitations. Bridges have been a field in which there has been a greater technical experimentation. History and technology are inseparable for understanding the evolution of architectural spatiality. The technological variety now offers a wide range of options [3], each with particular aspects, whether related to the dimensional ranges, construction or economic conditions. From a technical point of view, the construction is conceived as the election of the most appropriate choice for an specific problem. Therefore, a good understanding of the technical landscape is necessary for understanding the framework in which architectural production is performed.

[1] Historical view of large span bridge



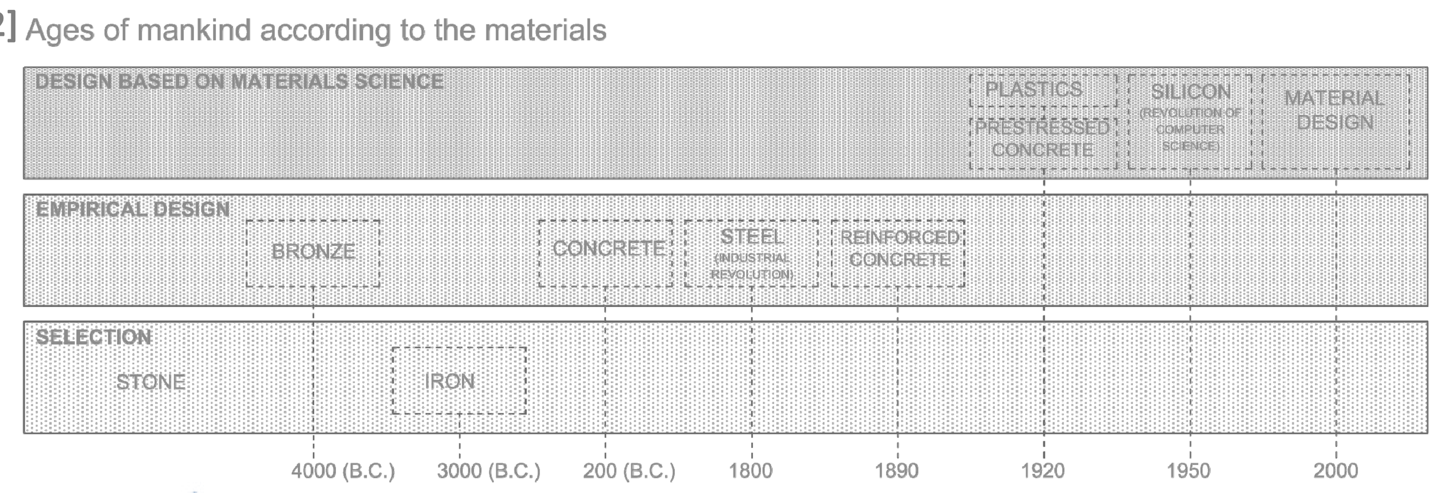
[4] Bridges that defined the dimensional limits of technology



Discoveries of material science

1.- 1713 - Abraham Darby I replaced charcoal as a source of heat in the iron foundry with reducing agent, using coke (fossil fuel). This combustible needed a taller furnace cuba, developing a new method to obtain cast iron.
2.- 1740 - Benjamin Huntsman developed his own method of steel production, obtaining a much harder material.
3.- 1783 - Henry Cort patented the puddling process.
4.- 1811 - Aubertôt proposed reuse of hot gases from blast furnaces, to perfect the process and reduce energy losses.
5.- 1828 - Neilson implements the proposal Aubertôt, optimizing the production process.
6.- 1834 - Wilhelm August Julius Albert was the first to use the *"Albert Cable"* in the Harz mines.
7.- 1842 - Hemp rope is replaced in the USA with steel cable.
8.- 1845 - Smith and Newall started developing a 7-strand wire rope and invented the wire drawing machine, important for the industrial production of wire rope.
9.- 1849 - In USA John Augustus Roebling began producing the cable of three sizes, formed by a set of 19 strand, organized in three groups of six around the core.
10.- 1850 - The first high-speed wire drawing machine appeared.
11.- 1856 - Bessemer method for steel production. The Impurities are removed from the molten metal by introducing air into the furnace, causing an oxidation process, enhanced by the temperatures of pig iron. In this moment began the rolled steel production.
12.- 1864 - Martin-Siemens Furnace appears, as combination of the method of Martin and Siemens furnace. This became the most common mean of steelmaking in UK and the USA in the second half of the nineteenth century.
13.- 1873 - California Cable, is a particular type of wire rope developed by Andrew Smith Hallidie, for trams of San Francisco. This solution is more expensive but has a longer life for the stress conditions to which the wires are subjected.
14.- 1889 - James Stone define in 1889 the method to produce a circular wire rope, with 6 fillings and 19 wires of the same size. The James Stone´s wire rope is one of the most used for general applications.
15.- 1900 - Electric furnaces allow the production of a steel of perfect purity, without presence of impurities such as phosphorus or sulfur. This furnace type allow a perfect combination of additives to obtain steel alloys.
16.- 1906 - The American chemist Leo Hendrik Baekeland, of Belgian origin, developed the Bakelite, the first commercial plastic.
17.- 1920-1930 - During the 1920s most plastics were born, such as: cellulose ethanoate (used for producing resins and fibers), polyvinyl chloride (PVC) (used in the production of pipes and coatings vinyl) and acrylic resins (used in the production of laminated glass and other products).
Other plastics developed in this period are: methyl methacrylate polymer (Plexiglas (in Spain), Perspex (UK) and Lucite (USA)), polystyrene resins (used as thermal insulation) and polytetrafluoroethylene (PTFE) (first synthesized in 1938, named Teflon in 1950).
All plastic materials had a great development throughout World War II, shortages of raw materials led to replace them by plastic materials, which were an *"inexhaustible"* resource.
In this period the wire rope production is perfected, allowing an increase in size and strength. This factor is responsible of evolutionary leap of suspended bridges.
18.- 1953 - Karl Ziegler developed a method to synthesize polyethylene.
19.- 1954 - Giulio Natta developed a method to synthesize polypropylene.

[2] Ages of mankind according to the materials



ESCUELA TÉCNICA SUPERIOR EDIFICACIÓN UNIVERSIDAD POLITÉCNICA DE MADRID

III International Congress on Construction and Building Research
14-16 December 2015